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PROBABILISTIC VISUAL SEARCH

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Dedication

For my family.

Acknowledgments

I would like to acknowledge the contribution of Nick Lange and Rick Thomas from the decision processes lab at the University of Oklahoma to my graduate school training. Lively discussions with Nick and Rick on memory retrieval greatly increased my understanding of long-term memory and inspired much of the work in the present dissertation.

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Table of Contents

List of Tables

List of Figures

Abstract

In the present dissertation I examine whether participants are able to use cues that provide probabilistic target information. On each trial, participants are presented with a search array and are asked to find a target and report an attribute of the target (e.g., its orientation). Prior to the onset of the search array, a background cue is presented that provides varying degrees of information regarding the color of the target in the upcoming search array. In Experiment 1, minimal differences in visual search performance (as assessed by reaction times) are found for background cues that are perfectly predictive and moderately predictive of the target color relative to a background cue that is entirely non-predictive. It is argued that participants were not selecting the features of target that were related to the background cues and thus not encoding this information into long-term memory. In Experiment 2, the stimuli in each search array are created such that in order to identify the target's orientation the entire target object needs to be selected, including its color. Thus, this ensures that participants are selecting the feature that is related to the background cue. In this experiment, visual search differences are found between background cues that perfectly predict and cues that partially predict the color of the target in the upcoming search from the background cue that is uninformative. However, Experiments 3a and 3b reveal that the participants in Experiment 2 were likely not using the background cues but were relying on target base rate information to improve search. In Experiment 4, the selection of the background cues is encouraged by periodically testing participants regarding the relationship between the background cues and associated target features. A difference is observed between Experiment 4 and 2 such that participants in Experiment 4 were

faster, particularly for those participants who learned the relationship between the background cues and its associated colors, suggesting that the participants in Experiment 4 were using the background cues to improve search. Finally, in Experiment 5 participants were eye tracked as they went through the same task as in Experiment 4. Eye track analyses revealed that there was strong guidance towards features that were associated with the background prompts. The results from the present dissertation suggest that the methodology employed is useful for understanding interactions between long-term memory, working memory, and attention.

Chapter 1: Introduction

During the past 30 years there has been substantial progress in the field of attention. One of the employed methodologies to understand attention is visual search. Participants are instructed to search for a "target" item (e.g., search for the red vertical bar) and this target is embedded within a visual array of distracter items (or is absent from the search array). In the 1980s much of the research in this domain focused on the perceptual dimensions of the task. For instance, as the similarity of the target to the distracters increases the more difficult the task becomes as evidenced by longer Reaction Times (RTs) and steeper set size slopes relative to when the target item is highly dissimilar to the target (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980).

Although a wealth of information has been accumulated regarding perceptual-based processes and attention, this focus moved the field away from studying the interactions of LTM and attention in a visual search task (e.g., Schneider & Shiffrin; 1977; Shiffrin & Schneider, 1977). Because we are rarely provided with target characteristics prior to deploying visual search in everyday circumstances, it seems prudent to study visual search where LTM plays a crucial component in attentional allocation. Fortunately, a resurgence has taken place in recent years in examining the role of LTM in visual search tasks. I will now discuss literature germane to LTM in visual search followed by a discussion of some crucial components that are missing in the present methodologies.

Chapter 2: Visual Search and Memory

Chun & Jiang (1998) had participants search for a rotated "T" amongst rotated "L" characters. Over the course of the experiment, some visual scenes were repeated (consistently mapped) whereas others were changed (varied mapping). Specifically, in the consistent mapping condition, each time a visual scene was repeated it retained the same spatial configuration (target to distracter locations) whereas for the varied mapping condition the target was in the same location, but the distracters were randomly placed within the scene. In the second half of the experiment, participants were faster in the consistent mapping condition relative to the varied mapping condition, suggesting that participants were able to exploit the regularities associated with consistently mapped scenes to locate the target faster than when these regularities were not present. This effect was later broadened by Chun & Jiang (1999) who had participants search for a geometric shape that was symmetrical across its vertical axis amongst geometric shapes that were not symmetrical across their vertical axis. Across the course of the experiment, a target was either paired with the same set of geometric shapes or paired with a random set of shapes for each presentation. Contrary to Chun & Jiang (1998), the spatial relationship between the target and distracters was randomized on each trial for both conditions. Even though participants could not use spatial regularities to inform search process, participants were still faster in the consistent mapping condition relative to the varied mapping condition, suggesting that again participants were able to pick up on the statistical regularities associated with the consistent mapping condition and use this information in the visual search task. The authors postulated that throughout the course of the experiment, the consistent pairing of a target with the same distracters led to cued retrieval of the target shape. In other words, viewing the same geometric shapes paired with the same target led Working Memory (WM) to be populated by the target shape that had been associated with the distracters in the past when presented with a consistent mapping cue. Because this shape information was more specific than the general one given at the beginning of the experiment (i.e., find the geometric shape that is symmetrical across its vertical axis), attention was guided towards the target in the visual scene, which corresponded to the content of WM (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989).

The contextual cueing paradigm has had a dominant influence over the study of visual search and LTM over the past decade and has included numerous extensions, including the replication of the effect using realistic stimuli (e.g., Brockmole & Henderson, 2006) and the finding that semantic information can guide search (Brockmole and Le-Hoa Vo, 2010). The main finding has been that previous experience can be used to help guide attentional processes in demanding visual search tasks when those environments are consistent in their presentation across time.

One important aspect of the environments that we encounter is that they are unlikely to remain constant across time, which also includes the targets that we are searching for. Although there are statistical regularities in the contextual cueing studies mentioned above, for the most part these environments could be described deterministically. In other words, for the consistent mapping condition the visual scenes are the same from trial to trial. Thus, when a consistently mapped scene is viewed, there is no ambiguity regarding the nature of the target (e.g., its location (Chun & Jiang (1998); or shape Chun & Jiang (1999)) from trial to trial, which is the methodology of many contextual cueing studies where one target location is associated with one cue. However, Chun & Jiang (1998; Experiment 6) did have an experiment where a cue was associated with two target locations and did find an effect such that the target was found faster for consistently mapped scenes relative to varied mapped scenes. However, subsequent research on this topic has demonstrated that only one spatial location is learned for a cue, even when that cue is associated with multiple target locations (Zellin, Conci, Muhlenen, & Muller, 2011). Specifically, Zellin et al., (2011) found that there was a "dominant" target location that became associated with a cue even when more than one target location is associated with that cue. The other "minor" target location associated with the cue showed minimal to negative contextual cueing effects. Only when the minor target locations were within a close distance of the dominant target were positive contextual cueing effects observed for minor target locations. Although this would suggest that participants are able to use multiple features/locations given a cue in a visual search context, other research has demonstrated that participants are able to use probabilistic information in a visual search task (Droll, Abbey, and Eckstein, 2009). However, it should be noted that Zellin's analysis is necessary to perform when a cue is associated with more than one target feature/location to determine whether participants were utilizing multiple target features given a cue (this type of analysis is used below).

Droll, Abbey, and Eckstein (2009) had participants search for a target contrast increment amongst distracter contrasts. Importantly, the target or distracter contrasts appeared within colored circles and the probability with which a particular colored circle would contain the target was manipulated. For instance, 60% of the time the contrast increment was contained within the black circle, 20% of the time it was contained within the orange circle, and 10% of the time it was contained within the purple circle. Over the course of the experiment, participants were able to use the color information to improve visual search performance, including perceptual decisions regarding the target. Additionally, participants were eye tracked while going through the experiment and were more likely to make correct saccades towards the target at the onset of the search array as the experiment progressed. Thus, participants were able to use their previous experience to effectively find the target in a probabilistic environment.

The Droll, Abbey, & Eckstein (2009) experiment contains an important aspect of everyday visual search that is typically not studied within the contextual cueing literature, namely that the environments that we encounter are probabilistic. However, one of the aspects of the Droll, Abbey, & Eckstein (2009) experiment that is missing is used in the contextual cueing literature, which is that cues are associated with aspects of the target (e.g., its location). Thus, it would be prudent to combine these two different methodological aspects into one methodology where cues are used and these cues are probabilistic in nature. For instance, when one cue is presented the target would always be associated with one color (e.g., red) whereas when another cue is presented the target could be associated with two colors (e.g., 80% of the time the target is red and 20% of the time the target is brown). Thus, this methodology allows for flexibility in that deterministic and probabilistic environments can both be assessed. Perhaps more importantly, however, the methodology is likely to be closer to the ecologies that we experience on a daily basis (i.e., probabilistic), which have been understudied within visual search when studying interactions of long-term, WM, and attention. Thus, in the present dissertation I plan to study how human participants learn and exploit probabilistic ecologies in a visual search task.

Chapter 3: Use of background cues in service of visual search

Experiment 1 was conducted to determine how well participants would be able to use probabilistic cues to inform visual search. Specifically, at the beginning of each trial participants were presented with a background cue. Following the background cue, participants were then presented with a brief fixation and the visual search array, while the background cue remained. The visual search array contained 12 colored ellipses that either contained an "X", "M", or "N" (see Figure 1). Eleven of the colored ellipses contained an "X" and one of the colored ellipses contained an "M" or "N."

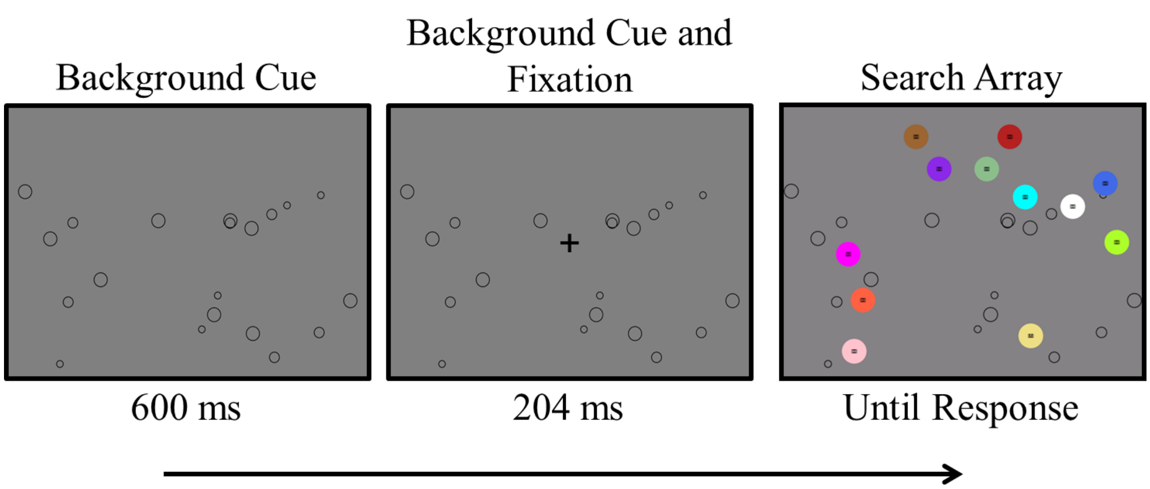

Figure 1: Schematic of the main components of each trial for Experiment 1. Participants were first presented with a background cue, which was then followed by a brief fixation. After the fixation, the search array was presented and it was the goal of participants to determine whether an "M" or "N" was in the search array.

Participants' goal of the visual search task was to report whether an "M" or "N" was in the search array (thus "M" and "N" were the targets) while avoiding the distracters (the "X's"). The probability that a target would appear on a particular colored disk given a cue was manipulated (see Table 1), such that the cue either had a deterministic relationship with a color (i.e., background 1) or a probabilistic relationship (i.e., background 2-background 4).

	C1	C2	C3	C4	C5	C6-C12
Background 1: 100	1.0	0.0	0.0	0.0	0.0	0.0
Background 2: 60/40	0.0	0.6	0.4	0.0	0.0	0.0
Background 3: 80/20	0.0	0.0	0.0	0.8	0.2	0.0
Background 4: Random	0.08	0.08	0.08	0.08	0.08	0.08

Table 1: Displays the contingencies between the background cues and the colors associated with the target. C = Color.

For the background 1: 100 condition, whenever the background 1 cue was presented the target of the visual search task was always associated (i.e., the "M" or "N" appeared on that colored ellipse) with Color 1 (C1). When the background 2 cue was presented 60% of the time the target was associated with C2 and 40% of the time it was associated with C3 and when background 3 was the cue the target was associated with C4 80% of the time and C5 20% of the time. When the cue was background 4, the target could be associated with one of any 12 colors in the experiment (randomly chosen on each trial). Participants went through 6 Epochs of the experiment and at the end of the experiment (i.e., after the last visual search trial) participants were asked whether they noticed a relationship between the background cues and the colors associated with the target. Following this, participants were tested regarding their knowledge (more details below).

I hypothesized that participants would be able to use the cues to inform their visual search processes. Specifically, I predicted that participants would be faster in finding the target as the diagnosticity of the cue increased based on the findings that cues can be used in deterministic environments (e.g., Chun & Jiang, 1998; Chun &

Jiang, 1999) and that participants are able to use probabilistic information in a visual search task (e.g., Droll et al., (2009)).

Method

Participants

Twenty-two participants (13 females; M_{age} = 19.9) from the University of Oklahoma participated in Experiment 1 for course credit. All participants reported normal or corrected-to-normal vision.

Stimuli and Apparatus

Stimuli were presented on a 17” monitor, controlled by a Dell computer with a 3 GHz Pentium 4 processor. Distance to the monitor was approximately 60 cm. Stimulus presentation and data recording were controlled via E-Prime 2 by PST, Inc.

The backgrounds were created by randomly placing 20 of the same geometric shape (with the size of the shape being randomly chosen between three different sizes) on a gray background (shapes used were circles, diamonds, squares, and triangles). This was done for each of the different backgrounds. Prior to each experimental session, four new backgrounds were created for each participant prior.

The following 12 colors were used in Experiments 1 (RGB values): blue violet (138, 43, 226), brown (153, 102, 51), cyan (0, 255, 255), light goldenrod (238, 221, 130), royal blue (65, 105, 224), magenta (255, 0, 255), tomato (255, 99, 71), firebrick (178, 34, 34), deep sea green (143, 188, 143), white (255, 255, 255), and green yellow (173, 255, 47). Each ellipse was roughly 2.3 cm (width) by 2.5 cm (height). Each ellipse contained a rectangle (0.5 by 0.4 cm) which contained an “X”, “M”, or “N” (0.2 by 0.4 cm).

In the visual arrays each of the 12 colored ellipses were placed randomly at one of 35 possible locations. The 35 different locations were based on (unseen) ellipses of different sizes, with 10 possible locations around the smallest ellipse (distance from the top or bottom of the ellipse to the center = 76.5 mm, distance from the outermost left or right position on the ellipse to the center = 72.5 mm), 15 possible locations around the middle ellipse (116 mm, 108 mm), and 10 possible locations around the largest ellipse (155 mm, 145 mm).

Procedure

When participants arrived for the experiment they were seated in front of a computer and read through and signed an Informed Consent. Participants then went through a detailed explanation of the experiment and were told to search for the “M” or “N” as quickly as possible. Participants were *not* informed of the different backgrounds that would be present during the experiment and what the different backgrounds meant (i.e., that some of the cues could be used to predict what colored ellipse (or ellipses) the target would appear on).

Participants initiated each trial by pressing the spacebar on the keyboard, this was followed by a fixation for 996 ms. Following the fixation, a background cue was presented (600 ms) followed by the same background cue with a central fixation, which was then followed by the visual search array. Participants were told to find the “M” or “N” as quickly as possible and press the f-key when the “M” was the target and the j-key when the “N” was the target. Although eye movements were not monitored, participants were instructed to fixate the cross until the search array was presented.

For every 40 trials (referred to as a block), beginning with the first trial, participants were exposed to the different pairing of the background and the target colors that reflected the statistical contingencies in Table 1. The relation between the background and its diagnosticity in predicting the associated target color is referred to as *cue validity*. For one background the cue validity was 100% (i.e., the target was always on one colored ellipse during the entire experiment given the background cue), referred to as the background 1: 100 cue validity condition. Another background had cue validities of 60% and 40% (background 2: 60/40 cue validity condition), that is 60% of the time the target was on one colored ellipse (e.g., blue) and the rest of the time (40%) the target was on another colored ellipse (e.g., green). The third background had cue validities of 80% and 20% (background 3: 80/20). For the final background, the color that the target was associated with was randomly chosen on each trial (background 4: Random). To give an example, say the square background is paired with the 60/40 condition (background 2: 60/40) and is presented for ten trials during a block. Given the 10 trials, the target would be on the blue colored ellipse on 6 trials and on the green colored ellipse for the remaining 4 trials. The trials for the 60/40 condition would be randomly interleaved amongst the other conditions (i.e., background 1: 100 &

background 4: Random).

Participants went through 12 blocks with 2 blocks creating an Epoch (i.e., block 1 + block 2 = Epoch 1; block 3 + block 4 = Epoch 2….block 11 + block 12 = Epoch 6). After each Epoch participants were required to take a 10 second break and informed that they could take as long of a break as they wanted before starting the next block.

It should be noted that each of the colored ellipses appeared for each of the different backgrounds. For instance, the background 1: 100 condition, where the target was always on the red colored ellipse (for instance), one distracter would always be on the red colored ellipse in the background 2: 60/40 condition, and the target would never be on the red colored ellipse for the background 2: 60/40 condition. In the background 4: Random condition, the target was free to appear on any colored ellipse, including those colors that were associated with the other conditions. At the beginning of the experiment the colors used for each of the different cue validity conditions was randomized (i.e., the colored ellipses that the target appeared on for the background 1: 100, background 2: 60/40, and background 3: 80/20 conditions were randomly chosen amongst the 12 different colors) and kept constant throughout the experiment.

After finishing the final trial of the visual search task (i.e., after the final visual search trial), participants were asked if they noticed a relationship between the backgrounds and the likelihood of the target being associated with a certain color (or colors). Following their response, participants were then asked to do a recognition task. On each trial of the recognition task, a background cue was presented followed by the search array. The colored ellipse that the target appeared on for each search array was either valid (i.e., the target in the search array was on a colored ellipse that it was during the experiment) or invalid. Participants were asked to indicate whether the colored ellipse that contained the target ever contained the target during the visual search task by either pressing the y-key (yes, it did) or the n-key (no, it did not).

Results

In all of the experiments presented below, participants were removed from analysis if they had an error rate of 15% or more in reporting the target for each trial, which removed one participant from the analysis in Experiment 1. Of those participants included in the analysis, there were orientation errors on 1.6% of trials. Trials where RTs were slower than 10,000 ms or faster than 200 ms were also excluded from analysis in Experiment 1 (less than 0.1%).

A repeated measures ANOVA with cue validity (100, 60/40, 80/20, Random) and Epoch (Epochs 1-6) as within subjects variables was performed. There was a main effect of Epoch such that participants had faster RTs at later Epochs relative to earlier Epochs, $F(5, 100) = 17.973$, $p < .001$, $\eta^2_p = .473$. There was a main effect of cue validity such that participants were fastest in the 100 cue validity condition, slowest in the Random condition with 60/40 and 80/20 in between 100 and Random ($F(3, 60) = 3.637$, $p = .018$, $\eta^2_p = .154$). Finally, there was not a significant interaction, $F(15, 300) = .585$, $p = .886$, $\eta^2_p = .028$ (see Figure 2).

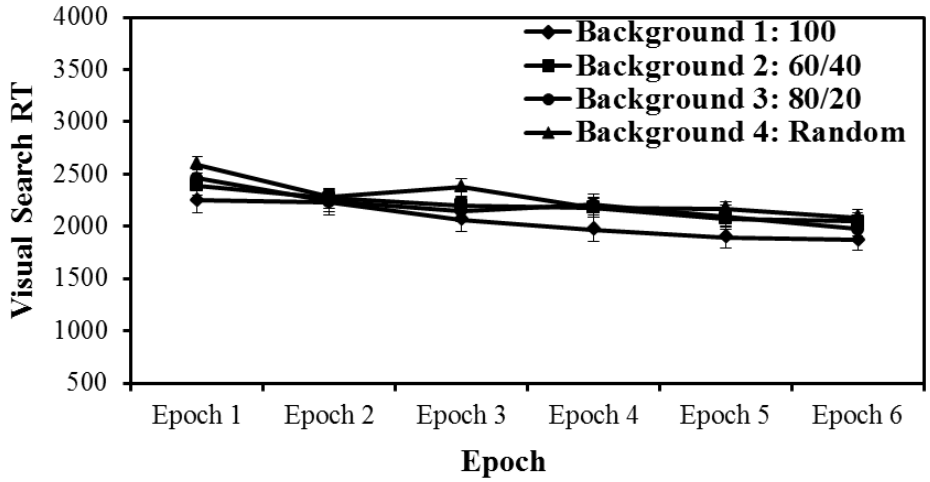

Figure 2: Reaction time performance as a function of Epoch and cue validity in Experiment 1. Error bars represent one standard error.

In order to assess differences towards the end of the visual search task, I first computed median values for each of the different cue validity conditions for Epochs 3, 4, and 6. I then took the mean of those median values for each participant to compare the different cue validity conditions. A repeated measures ANOVA revealed a significant main effect of cue validity, $F(3,60) = 2.810$, $p = .047$, $\eta^2_p = .123$, which was followed by Bonferonni pairwise comparisons. The 100 cue validity condition (M = 1911.2), was significantly different from the random cue validity condition (M = 2143.7; $p = .021$). However, the other comparisons were not significant (all p's > .15). Because neither the 60/40 nor 80/20 cue validity conditions were significantly different from chance, I did not examine dominant and minor target features for Experiment 1 for backgrounds 2 and 3.

Of the twenty-one participants included in the analysis, ten indicated that they noticed a relationship between the background cues and the color of the target. Overall accuracy in the recognition task was 51.4%. For the different cue validity conditions, recognition accuracy was 54.7% for the 100 cue validation condition, 50% for the 60/40 condition, and 51.2% for the 80/20 cue validity condition. Those participants that indicated they noticed a relationship between the background cues and the color of the target had accuracy scores of 50%, 45%, and 55.5% for the 100, 60/40, and 80/20 cue validity conditions respectively. Thus, participants overall did not have explicit awareness of the relationship between the cues and the color of the target. Most importantly, however, is that participants were not generally faster as cue validity increased, as was hypothesized would happen.

Discussion

Although there were some indications that participants were able to use the background cues to find the target effectively, the results were modest. The only difference amongst the different cue validity conditions was between the 100 cue validity condition and the random cue validity condition and the effect was not strong. It seems unusual that participants were not able to use the statistical regularities in the environment in order to reduce the perceptual demands of the visual search task, as other studies have found such an effect (e.g., Droll, Abbey, & Eckstein, 2009). However, in the study by Droll et al., participants did not have to learn conditional dependencies (e.g., given this cue the target is likely to be associated with the red or yellow ellipse), but merely needed to learn the overall base rates that the target would be associated with particular color. This can be contrasted with Experiment 1 where the cue presented prior to the onset of the search array changes the probability that a particular color would be associated with the target. Thus, it could be that participants are unable to learn probabilistic information in the type of environment where cues provide diagnostic information regarding the nature of the target. However, there are a number of other possibilities that may provide an explanation of the present results. Below, I explore the possibility that the lack of statistical learning in service of visual search observed in Experiment 1 was due to a lack of selection of relevant aspects of target features on each trial.

Selection has long been an important topic within the visual search literature. For instance, Treisman & Gelade (1980) argued that selection provides the "glue" that binds the features of an object together. Without this selection process, features are not combined in the environment to form coherent objects (Treisman & Schmidt, 1982). More germane to the present investigation is a series of studies conducted by Turke-Browne, Junge, and Scholl (2005) who examined the automaticity of visual statistical learning. Specifically, in their task participants were sequentially presented with a series of shapes. Throughout the course of this "familiarization phase" shape sequences were grouped into triplets and were repeated throughout the course of training (e.g., Shape A, was followed by Shape B, which was followed by Shape C). Critically, the shapes were one of two colors (i.e., red or green) and the triplets for each of the items were interleaved such that the stream for one set of items was intermixed with the group of another. For instance, if ABC shapes were one group and DEF were another then the stream of shapes a participants may see might look like DABEFC. Participants were merely to respond to a shape of a particular color when it repeated during the training phase (e.g., responding to the second C in the sequence DABEFCC). Thus, participants were only to attend to one color during the course of training. After the training phase, participants were presented with a set of triplet shapes that either were grouped together (temporally) during training or were not and participants performed a familiarity test. The results indicated that participants only learned the statistical contingencies for the shapes that were attended to during the experiment, highlighting the importance of selection in the learning of statistical regularities.

In Experiment 1, participants were asked to search for an “M” or an “N” in each visual array and this target was presented on top of colored ellipses. Due to this set-up, it is likely that participants were rarely selecting the colored ellipse associated with the target on each trial and thus were not able to use this information for visual search. In other words, the goal of the participant was to try and find the “M” or “N” as quickly as possible. Performing this task does not require a selection of the colored ellipse appearing beneath the target. This can be contrasted with the set-up of Turke-Browne et al., (2005) where during the training phase participants were to attend to shapes of a particular color (thus, both the color and the shape were selected during each presentation of a shape). Thus, to encourage selection of the items in the search arrays within the present paradigm, in Experiment 2 a rotated “T” character served as the target on each trial and participants were to fine the “T’ and indicate its orientation (i.e., tilted 90 degrees left or 90 degrees right). These “T” characters were of a specific color and thus when the target was selected to determine its orientation, the color of the “T” would be selected as well. This selection process should then allow for exploitation of the statistical regularities occurring in the ecology that participants are exposed to (i.e., the cue to target color relationships).

Two other significant changes were made in Experiment 2. The background cue was presented for a longer period of time, as previous research has shown that an increase in cue presentation allows for the ability to better exploit statistical regularities in a visual search task (Kunar, Flusberg, & Wolfe, 2006). Because of this change, the time of the experiment was increased considerably and the 80/20 condition cue validity condition was not used in the rest of the reported experiments. Finally, the last significant change made in Experiment 2 relative to Experiment was is that the participants were given feedback regarding their response on each trial, which has been shown in some studies to influence the learning of statistical regularities (e.g., Droll et al., 2009), but does not seem to be a crucial component (e.g., Fiser & Aslin, 2001, Turke-Browne et. al., 2005).

Chapter 4: Ensuring selection of target information

In Experiment 2 participants were asked to respond to the orientation of a “T” (rotated 90 degree clockwise or 90 degrees counterclockwise), while ignoring modified rotated “L” characters (i.e., modified to look more like a rotated “T”) in a visual array. Each visual array contained 14 different items (13 distracters and 1 target), with each item being unique in color. Table 2 provides the relationship between the background cues and the color of the target in Experiment 2.

	C1	C2	C3	C4 - C14
Background 1: 100	1.0	0.0	0.0	0.0
Background 2: 60/40	0.0	0.6	0.4	0.0
Background 3: Random	0.07	0.07	0.07	0.07

Table 2. Provides the contingency table for how the backgrounds (backgrounds) were paired with the different colors (C1-C14) for Experiments 2, 4 & 5.

Participants went through 360 trials (i.e., 6 Epochs, 1 Epoch = 60 trials). As in Experiment 1, participants were not informed at the beginning of the experiment that a statistical relationship existed between particular background cues and the color associated with the target. Following the final visual search trial, participants were asked whether they noticed a relationship between the background cues and the color of the target and performed a recognition task, similar to Experiment 1.

Method

Participants

Twenty-two participants (10 females; M_{age} = 19) from the University of Oklahoma participated in Experiment 2 for course credit. All participants reported normal or corrected-to-normal vision. Four participants were excluded from the analysis due to high error rates (error rates ≥ 15%) during the visual search task, leaving 18 participants for the analysis.

Stimuli and Apparatus

Stimuli were presented on a 17" monitor, controlled by a Dell computer with a 3 GHz Pentium 4 processor. Distance to the monitor was approximately 60 cm. Stimulus presentation and data recording were controlled via E-Prime 2 by PST, Inc.

Because of the targets used in Experiment 1 ("M" and "N"), it would have been difficult or impossible to discriminate the target (which was black) on particular colored ellipses (e.g., black). This was no longer a constraint when using a rotated "T" color as the target was not embedded on a colored item but was the determined by its shape (a "T"). The removal of this constraint allowed for a more varied set of hues in Experiment 2 relative to Experiment 1. The following 14 colors were used in the rest of the experiments (RGB values): black (0,0,0), blue (0,0,255), brown (153,102,51), cyan (0,255,255), green (0,128,0), lime (0,255,0), magenta (255,0,255), maroon (128,0,0), orange (255,165,0), pink (255,192,203), red (255,0,0), tan (210,180,140), white (255,255,255), and yellow (255,255,0). All the stimuli (the T's and L's) in the visual search array were roughly 22 mm x 22 mm.

Procedure

Most aspects of Experiment 2 were the same as in Experiment 1 with the following exceptions. At the beginning of each trial participants were provided with a background cue (2004 ms) followed by a search array. When the search array was presented, participants were asked to search for a rotated "T" and report its orientation by pressing the f-key when the "T" was rotated 90 degrees to the left and the j-key when it was rotated to the right. Following their response, participants were presented with a brief mask (68 ms) followed by a feedback screen (500 ms). Participants went through 6 Epochs with each Epoch consisting of 60 trials (360 trials total).

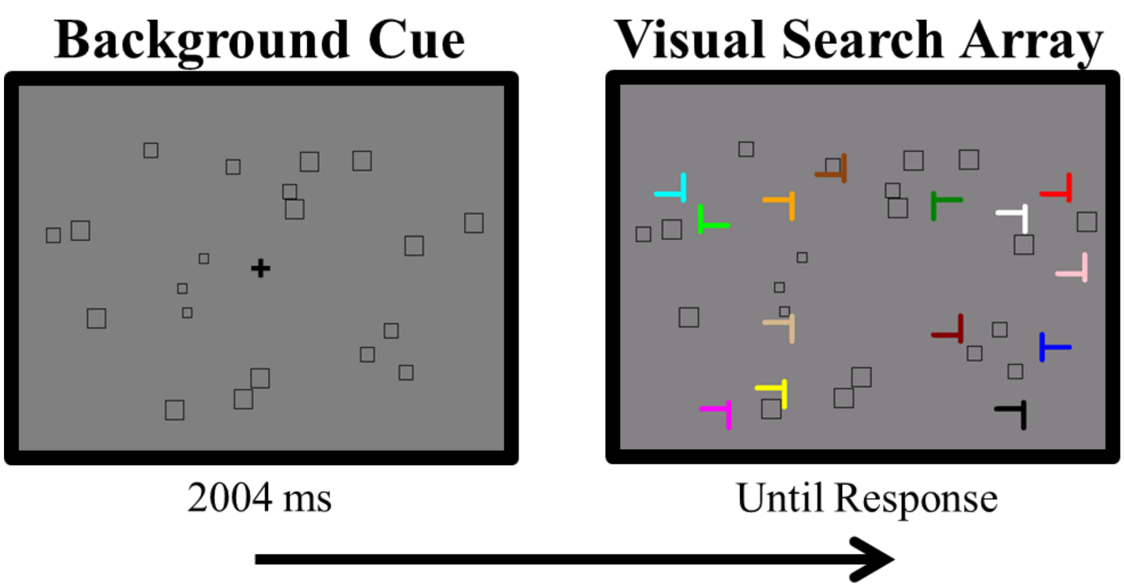

Figure 3: Schematic illustration of the main components of a trial for Experiments 2-5 in the present study.

<u>Results</u>

Trials in which the orientation of the target was mis-reported (4.19 %), as well as trials with RTs faster than 200 ms or slower than 10,000 ms (2.66 %) were removed prior to analysis.

A repeated measures ANOVA was calculated with Epoch (1-6) and cue validity (100, 60/40, Random) as within-subject factors. A main effect was found for Epoch ($F(5, 85) = 8.362$, $p < .001$, $\eta^2 p = .33$) and cue validity ($F(2, 34) = 32.238$, $p < .001$, $\eta^2 p = .655$) such that participants were faster as Epoch and cue validity increased. An interaction was observed ($F(10, 170) = 3.745$, $p < .001$, $\eta^2 p = .181$, see Figure 4).

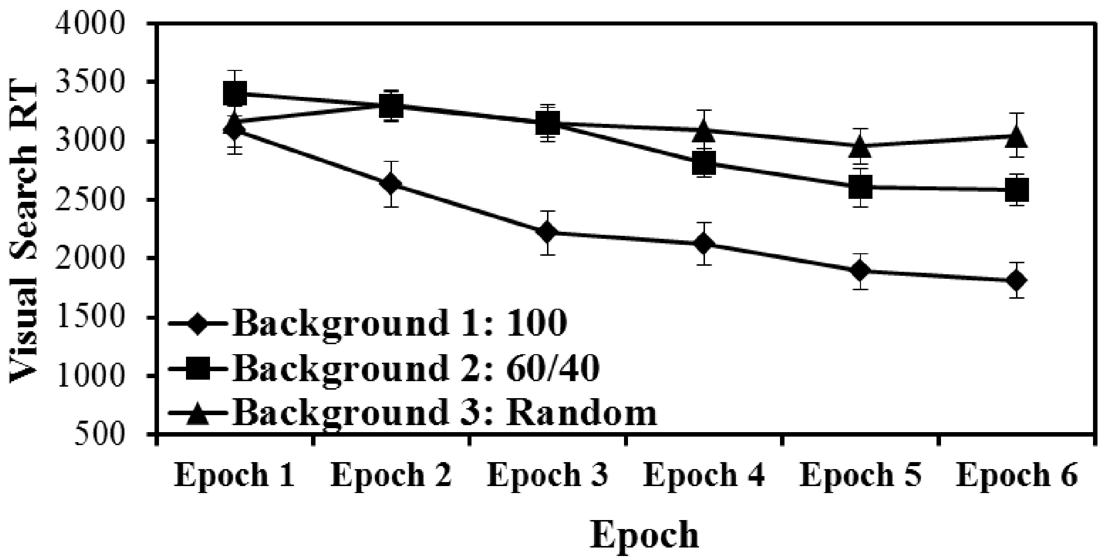

Figure 4: Reaction time performance as a function of Epoch and cue validity in Experiment 2. Error bars represent one standard error.

To examine visual search performance towards the end of Experiment 2, I next collapsed across the last 3 epochs for each of the cue validity conditions for analysis as in Experiment 1. A within subjects repeated measures ANOVA revealed a significant main effect of cue validity $F(2, 34) = 30.31$, $p < .01$, $\eta^2_p = 641$. Pairwise comparisons revealed a significant difference between all three conditions such that the 100 (M = 1942.1) cue validity condition was significantly different from the 60/40 (M = 2667.1) cue validity condition ($p < .001$) and the random cue validity condition ($p < .001$). The 60/40 cue validity condition was significantly different from the random (M = 3033.8) cue validity condition ($p = .003$).

Because the target for the 60/40 cue validity condition was found significantly faster than the target for the random cue validity condition, I next examined the dominant and minor target features for the 60/40 condition. As discussed above, this analysis was conducted to determine whether participants learned that the background 2 cue was associated with multiple target features (see Zellin et al., 2011). To perform this analysis, I collapsed across the 60 condition and the 40 condition for the last 3 Epochs. The dominant feature was the target feature with the fastest RT and the minor feature was the feature that was associated with the target with the longest RT. For instance, if the 60 condition has a mean value of 1200 ms and the 40 condition has a mean value of 1600 ms then the 60 condition would be the dominant feature and the 40 condition would be the minor feature, which could vary person-to-person. I next compared the dominant and minor features with each other and to the other cue validity conditions (background 1: 100 and background 3: Random). A repeated measures ANOVA revealed a main effect of target type, $F(2, 51) = 26.209$, $p < .001$, $\eta^2_p = 607$. The target when background 1 was the cue was found significantly faster than the dominant target feature (M = 2433) when background 2 was the cue ($p = .032$). The dominant feature was found significantly faster when it was the target relative to when the minor feature (*M* = 2899.2) was the target ($p < .001$). However, there was no difference in RTs when the minor feature was the target relative to when background 3 was the cue ($p = 1.0$).

Seven out of the 18 participants (38.88%) indicated that they had noticed a relationship between the background cue and the likelihood of the target being a particular color. To examine participant's accuracy in the recognition task I only considered the 100 and 60/40 cue-validity conditions. The overall accuracy rate for the recognition task was at chance level (50.93%). Accuracy rates for the different cue validity conditions were 55.56%, and 48.61% for the 100 and 60/40 cue validity conditions. Participants who indicated that they recognized a relationship between the background and the likelihood of the target being a particular color were no better at the recognition task, with accuracy rates of 50% for both the 100 and 60/40 conditions.

Discussion

The results from Experiment 2 suggest that participants were able to use the cue information to simplify the perceptually demanding search task. Specifically, participants were faster as cue validity increased such that the target was found fastest when the background 1 cue (i.e., deterministic) was presented prior to the search array and slowest when the background 3 cue (random) was presented before the search array. Participants were also able to learn to utilize the background 2 cue as evidenced by faster RTs when background 2 was the cue relative to the RTs for background 3. These results provide support for the claim made in the introduction for Experiment 2 that the “T” stimuli used would lead to selection of both the color of the target as well the shape information on each trial. Because participants had to determine the orientation of the target “T” to report its orientation, it is assumed that this selection process occurred for the color of the target information as well. This selection process allows for exploitation of the statistical regularities encountered in the environment (Turke-Browne et. al., 2005), namely the color of the target given the cue in Experiment 2.

Although participants were faster as cue validity increased in Experiment 2, participants performed poorly in the recognition task. Specifically, participants were not able to explicitly distinguish the target colors that were associated with each background cue even after extensive training (120 trials for each background cue). This leads to two likely possible explanations regarding the performance of participants in the visual search task: 1) either participants were utilizing the cue information at an implicit level of awareness (e.g., Chun & Jiang, 1998; Chun & Jiang, 1999) or 2) the cues were not utilized at all for the visual search task. I now consider the first possibility.

One of the striking aspects of the contextual cueing effect is its implicit nature. Specifically, participants are not able to distinguish consistently mapped arrays relative to varied mapping arrays. As mentioned above, in the Chun & Jiang (1998) experiment the search arrays’ spatial configurations were either consistent throughout the experiment or varied from trial-to-trial. At the end of the experiment participants were either presented with an array that they had seen repeatedly throughout the experiment (i.e., a consistent mapped scene) or an array that they had never seen before.

Participants were to issue “old” or “new” judgments to each array. Interestingly, participants were not able to distinguish between arrays they had repeatedly seen before from those they had not, even though participants were faster to find the target in the consistent mapping condition relative to the varied mapping condition, an effect that was later replicated (Chun & Jiang, 1999). Thus, the use of the cues in Experiment 2 could be similar to that of the cues in the contextual cueing literature in that participants are able to reap the benefits of the cues without necessarily recognizing the relationship between the cues and the color of the target. This could be an automatic retrieval process from LTM in response to a particular cue and then search would be based on this retrieved information as suggested by Chun & Jiang (1999). Additionally, the finding in Experiment 2 that the minor feature was not found significantly faster relative to the random cue validity condition suggests that the results of Experiment 1 may be similar to that of contextual cueing as participants were unable to utilize more than one target feature for a given cue (Zellin et al., 2011).

Another possibility regarding the results from Experiment 2 is that participants were not using the cues at all to help inform their visual search processes. This is a possibility as participants were still quite slow in Experiment 2 for background 1 and background 2. For instance, when background 1 was the cue the target was found in roughly 2 seconds, which is still quite a bit faster than the random cue validity condition. However, if knowledge of the color of the target can be predicted with absolute certainty, then participants should be able to find the target much faster than they did based on the heterogeneous set of colors used. Why then were participants able to find the target faster as the diagnosticity of the cue increased? In Experiments 1 and 2 the diagnosticity of the cue was manipulated via base-rate information of the different target colors. Therefore, participants could simply pick up (either explicitly or implicitly) on the base rate information regarding the color of the target and participants would still be faster as cue validity increased. For instance, regardless of background cue, C1 is most likely to be associated with the color of the target followed by C2 and C3. Thus, participants may simply have been searching for the target based on its likelihood of being a specific color. That is, participants were not conditionalizing when presented with a cue prior to the search array (i.e., p(color of the target|background cue). One explanation for this is that just as participants were likely not selecting the colored ellipses in Experiment 1, participants in Experiments 1 and 2 were not selecting the background cue on each trial. Not selecting the cue makes it less likely (or perhaps impossible) for participants to use the cue as a retrieval of associated target characteristics (e.g., color).

To distinguish between the two possible explanations described above, two separate experiments were conducted (Experiment 3a and Experiment 3b). As will be described below, there are different predictions for these experiments depending on whether participants were using the cues in Experiment 2. In Experiment 3a the diagnosticity of the background cue was eliminated, thus participants would not be able to use the background cue information to find the target and would only be able to rely on base rate information. If the explanation that cues were used at an implicit level of awareness is true, the RT results from Experiment 2 should be significantly different than Experiment 3a such that participants should be faster in Experiment 2 than Experiment 3a. The reason for this is that the diagnostic information available to participants in Experiment 2 will not be available to participants in 3a. However, if participants were not using the cue information at all, then there should be no differences between the respective cue validity conditions of Experiment 2 to the cue validity conditions of Experiment 3a.

In Experiment 3b the environments for each array was changed such that colors associated with one background never appeared for another background. For instance, C1 would only appear as the target when background 1 is the cue and would not appear as a distracter for background 2 or as a target not distracter for background 3. If participants are using base rate information to guide search, it is assumed that items in WM that do not correspond to any objects in the perceptual field will quickly drop out of WM (Lange, Thomas, Buttaccio, & Davelaar, 2012; Usher & Davelaar, 2002) and will be replaced by other likely target features. However, if participants are using the background cues, then no RT differences are expected as participants will only retrieve and maintain in WM the likely target colors given the cue.

Chapter 5: Examining whether participants were utilizing background prompts in Experiment 2.

Experiment 3a

The results from Experiment 2 provide support for the claim that participants are able to use cue information to simplify a perceptually demanding visual search task. However, it is unclear whether participants in Experiment 2 were relying on overall base-rate information to inform search as opposed to conditionalizing on the background cue prior to the onset of the search array. Experiment 3a sought to test this possibility by eliminating the diagnosticity of the cues presented prior to the search array. Specifically, participants were presented with a cue, however, the same cue was presented prior to each search array. For instance, if background 1 was a circle background, then a circle background was presented prior to C1-C14 being a target. Thus, participants would only be able to rely on base-rate information to guide search. If there is no significant difference between the respective cue validity conditions of Experiment 2 to Experiment 3a, then this would suggest that participants were not using the cues in Experiment 2. However, if the RTs are faster for the cue validity conditions of Experiment 2 relative to Experiment 3a, then it would suggest that participants were using the cues at an implicit level of awareness in Experiment 2.

	C1	C2	C3	C4 - C14
Background 1: 100	1.0	0.0	0.0	0.0
Background 1: 60/40	0.0	0.6	0.4	0.0
Background 1: Random	0.07	0.07	0.07	0.07

Table 3: Provides the contingency table for how the randomly selected background was paired with the different colors (C1-C14) in Experiment 2.

Method

Participants

Sixteen participants (13 females; M_{age} = 19.6) from the University of Oklahoma participated in Experiment 3a for course credit. All participants reported normal or corrected-to-normal vision. One participant was excluded from the analysis due to a high error rate (error rate ≥ 15%), this left 15 participants for the analysis.

Procedure

The same procedure used in Experiment 2 was used in Experiment 3a with the following exceptions. Only one background cue was used during the entire experiment such that one background was chosen randomly at the beginning of the experiment (i.e., the circle, square, or triangle background) and was paired with the different cue validity conditions. For instance, if the circle background was chosen at the beginning of the experiment then a circle background would be presented prior to and accompanying the 100, 60/40, and Random cue validity search arrays. At the end of the experiment participants were first asked whether they noticed that the target was more associated with some colors than others. After answering, participants were then asked to rank order the four most prevalent colors that were associated with the target during the experiment.

Results

Error trials were excluded from the analyses (3.5 %) as well as trials with RTs faster than 200 ms and slower than 10,000 ms (2.5%). Errors were not analyzed.

A repeated measures ANOVA was calculated with Epoch (1-6) and cue validity (100, 60/40, Random) as within-subject factors. A main effect was found for Epoch ($F(5, 70) = 13.694$, $p < .001$, $\eta^2p = .494$) and cue validity ($F(2, 28) = 15.125$, $p < .001$, $\eta^2p = .519$). Participants were faster as Epoch and cue validity increased. A significant interaction was also observed ($F(10, 140) = 2.309$, $p = .015$, $\eta^2p = .142$, see Figure 5).

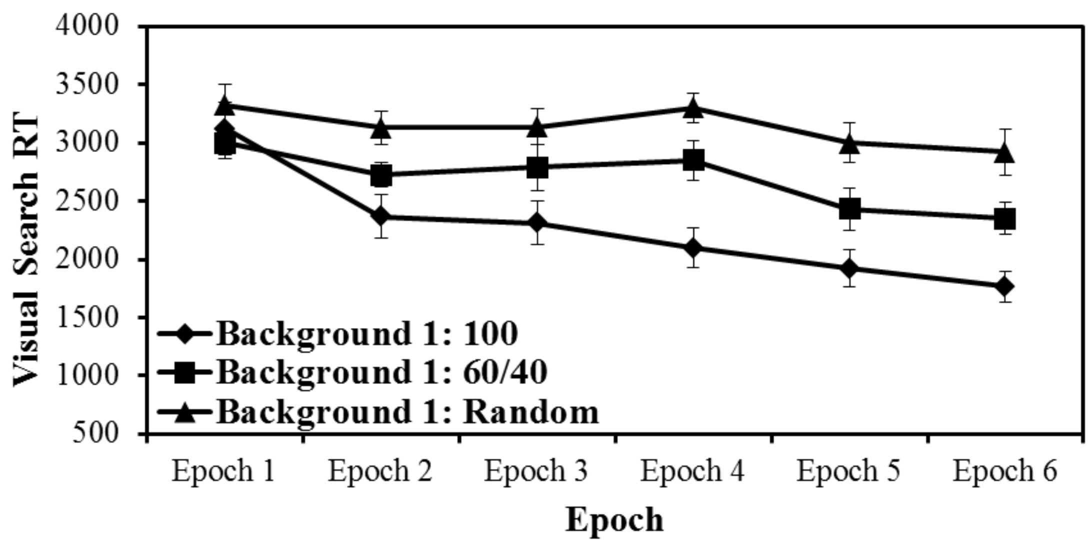

Figure 5: Reaction time performance as a function of Epoch and cue validity in Experiment 3a. Error bars represent one standard error.

I next collapsed across the last three Epochs and compared the different cue validity conditions. A within-subjects ANOVA revealed a significant main effect of cue validity, $F(2,28) = 16.668$, $p < .001$, $\eta^2_p = .544$. Pairwise comparisons revealed a significant difference between all three conditions such that the 100 ($M = 1926.8$) cue validity condition was significantly different from the 60/40 ($M = 2544.5$) cue validity condition ($p = .025$) and the random ($M = 3073.4$) cue validity condition ($p < .001$). The 60/40 cue validity condition was also significantly different from the random cue validity condition ($p = .029$).

Because participants were asked to name the most likely colors of the target, the data could be discussed in a number of ways. Only 2 (out of the 15) participants were able to order the colors from most to least prevalent in perfect order (i.e., 100, 60, 40). However, more than half of the participants (8 out of 15) were able to name the 3 most prevalent colors and 10 out of 15 were able to name 2 of the most prevalent colors. More than half (8 out of 15) of the participants also indicated the most prevalent color first. When conditionalizing on participants that indicated that they noticed that the target was more likely to be certain colors than others (9 out of 15), 77.77% (7 out of 9) indicated all 3 colors and all of them indicated at least 2 colors (not necessarily in the correct order though).

To compare whether there were RT differences between Experiments 2 and 3a, I ran an ANOVA with cue validity (100, 60/40) as a within-subjects variable and Experiment (Experiment 2, Experiment 3a) as a between subjects variable followed by a Bonferonni post-hoc analysis. The ANOVA revealed a significant main effect of cue validity, ($F(1,31) = 30.554$, $p < .001$, $\eta^2_p = .496$), but neither the Experiment main effect

($F(1,31) = 0.221$, $p = .641$, $\eta^2_p < .01$) nor the interaction, ($F(1,31) = 0.195$, $p = .662$, $\eta^2_p < .01$) were significant. A post-hoc analysis revealed that the 100 Experiment 3a cue validity condition was not significantly different from the respective Experiment 2 condition ($p = 1.0$) and the same was true when comparing the 60/40 conditions ($p = 1.0$). The similarity in RT results suggests that participants in Experiment 2 were not utilizing the cue information to improve their visual search performance.

Experiment 3b

Experiment 3b was conducted to provide corroborating evidence to the conclusion of Experiment 3a. In Experiment 3b the target colors were separated by background cue such that C1 never appeared as a distracter when background 2 was presented or as a distracter or target when background 3 was presented. Likewise, C2 and C3 never appeared as a distracter when background 1 was presented nor as targets or distracters when background 3 was the cue. Table 4 provides the relationship between the cues and the target color.

	C1	C2	C3	C4-C14	C15	C16	C17
Background 1: 100	1	N/A	N/A	0	0	0	N/A
Background 2: 60/40	N/A	0.6	0.4	0	0	N/A	N/A
Background 3: Random	N/A	N/A	N/A	0.07	0.07	0.07	0.07

***Table 4*. Displays the contingencies between the background cues and the colors associated with the target. C = Color.**

It is assumed that if participants are only relying on base rate information to drive visual search, then they should have faster RTs in Experiment 3b relative to Experiment 2. The reason for this is that retrieved target features will not be used if nothing in the search array matches the retrieved features. This will cause those features to quickly drop out of WM (Lange, Thomas, Buttaccio, & Davelaar, 2012; Usher & Davelaar, 2002). However, if participants are using the background cues, then participants should have equivalent RTs in Experiment 3b relative to Experiment 2 as the correct colors given the background cue are already resident in WM due to the retrieval process.

Method

Participants

Fifteen participants (11 females; M_{age} = 19[1]) from the University of Oklahoma participated in Experiment 3b for course credit. All participants reported normal or corrected-to-normal vision. Four participants were excluded from the analysis due to a high error rate in reporting the orientation of the target (error rate ≥ 15%), leaving 11 participants for the analysis.

Stimuli and Apparatus

The same stimuli and apparatus used in Experiment 2 were used in the Experiment 3b with the following exceptions. Three new colors were added to the

[1] One participant entered their age as “0.” Because it is unlikely that this person was in fact 0 years old, this value was not included in the reported mean age.

experiment and these were Navy (0, 0, 90), Olive (128, 128, 0) and Teal (0, 128, 128).

Procedure

As mentioned above, Experiment 3b was similar to Experiment 2 except that colors that were associated with the target for certain backgrounds never appeared as targets or distracters for the other backgrounds. For instance, C1 was never a distracter when background 2 was the cue nor was it a distracter or a target when background 3 was the cue. C2 and C3 appeared as targets for background 2, but were never distracters for background 1 nor targets or distracters from background 3. At the end of the last Epoch, participants performed a recognition task, similar to that of Experiment 2.

Results

Error trials were excluded from the analyses (3.8 %) as well as trials with RTs faster than 200 ms and slower than 10,000 ms (2.1%). Errors were not analyzed.

A repeated measures ANOVA was calculated with Epoch (1-6) and cue validity (100, 60/40, Random) as within-subject factors. A main effect was found for Epoch ($F(5, 50) = 10.523$, $p < .001$, $\eta^2 p = .513$) and cue validity ($F(2, 20) = 31.792$, $p < .001$, $\eta^2 p = .761$) such that participants were faster as Epoch and cue validity increased. A significant interaction was also observed ($F(10, 100) = 3.351$, $p = .001$, $\eta^2 p = .251$, see Figure 6).

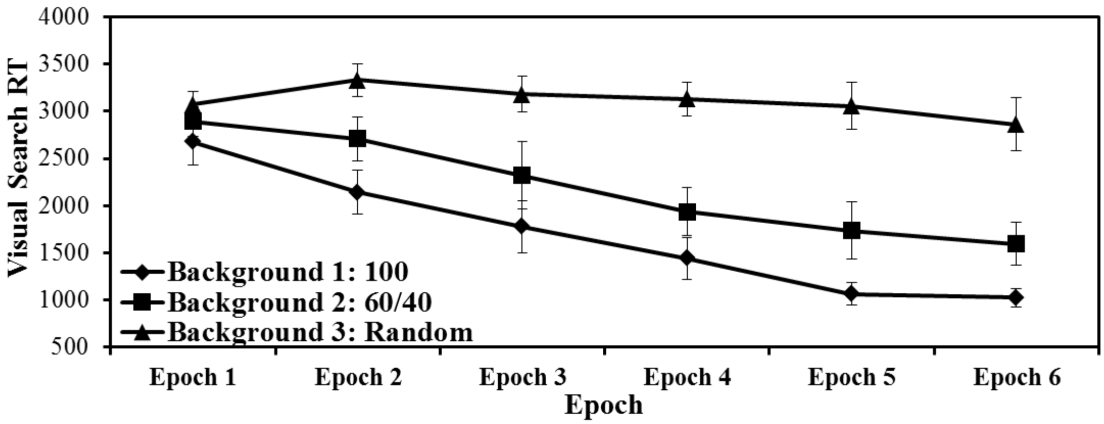

Figure 6: Reaction time performance as a function of Epoch and cue validity in Experiment 3b. Error bars represent one standard error.

Collapsing across the last 3 Epochs revealed a significant main effect of cue validity, $F(2,28) = 34.377$, $p < .001$, $\eta^2_p = .775$. Pairwise comparisons revealed a significant difference between all the 100 ($M = 1177.4$) and the random ($M = 3016.7$) cue validity condition ($p < .001$). The 60/40 (1756.9) cue validity condition was significantly different from the random cue validity condition ($p = .002$). There was a marginal difference between the 100 and 60/40 cue validity conditions ($p = .054$).

To compare whether there were RT differences between Experiments 2 and 3b, I ran an ANOVA with cue validity (100, 60/40) as a within-subjects variable and Experiment (Experiment 2, Experiment 3a) as a between subjects variable followed by a Bonferonni post-hoc analysis. The ANOVA revealed a significant main effect of cue validity, ($F(1,27) = 28.272$, $p < .001$, $\eta^2_p = .512$). There was an Experiment main effect ($F(1,27) = 18.875$, $p < .001$, $\eta^2_p = .411$), such that participants were faster in Experiment 3b relative to Experiment 2. The interaction was not significant, $F(1,27) = 0.352$, $p = .558$, $\eta^2_p = .013$ (see Figure 7).

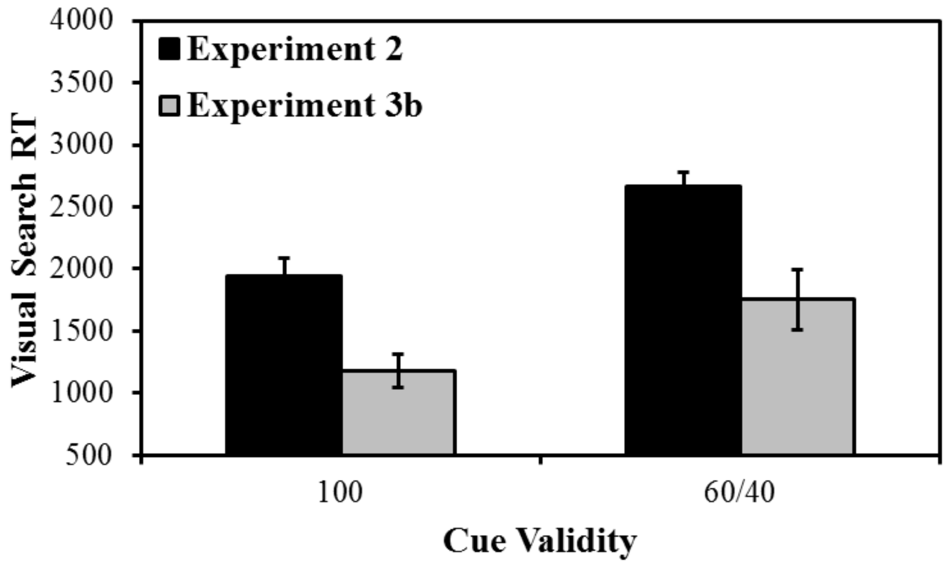

Figure 7: A comparison of the 100 and 60/40 cue validity conditions of Experiment 2 to the respective conditions of Experiment 3b. Error bars represent one standard error.

The post-hoc analysis revealed that the 100 cue validity condition for Experiment was marginal relative to the Experiment 3b condition (p = 0.055). There was a significant difference when comparing the respective 60/40 conditions (p = 0.034). The finding of the Experimental main effect and the significant 60/40 difference suggests that participants were able to use the separability of the color targets in the visual search task to improve their visual search performance in Experiment 3b. In other words, Experiment 3b provides further support for the claim that participants in Experiment 2 were not using the cues to inform search.

Discussion

Experiments 3a and 3b suggests that participants were not using the cues in Experiment 2 to improve visual search. Specifically, in Experiment 3a where the background cues were non-diagnostic, participants were just as fast to find the target for the respective cue validity conditions relative to Experiment 2, where the cues did provide diagnostic information. In addition participants were faster in Experiment 3b relative to Experiment 2, where there was separation between the cues and the target colors for the background 1 and background 2 cues.

The combined results of Experiments 1-3b beg the question of whether participants are indeed able to learn the relationship between background cues and target characteristics. As suggested above, it seems likely that participants were not selecting the background cue on each trial. The reason may be that participants had no reason to select the background cues as it had nothing to do with their primary task of searching for the rotated "T" in the search array. Participants were not informed regarding the diagnosticity of the cues, therefore participants likely ignored the background cues. It may seem odd that participants were not selecting the cue as on each trial participants were first presented with a gray screen, which was then followed by a background cue and finally the search array, with the background cue still appearing in the background of the search array. However, the ability of individuals to not notice information is well known (e.g., Simons & Levin, 1997). It is possible that participants were merely preparing for each trial and did not notice the fact that: 1) the screen went from gray to being filled with shapes and 2) that the background was associated with the color of the target. Because of this inability to notice that certain backgrounds were paired with particular target colors, participants were not able to pick up on the statistical regularities (Turke-Browne et. al., 2005). In Experiment 4 I tested whether participants would be able to learn the relationship between the background cues and the targets colors.

Chapter 6: Using knowledge tests to encourage use of background cues

In Experiment 2, participants were not using the cues to limit their search process to relevant colors in each search array. Although participants were able to use base rate information to improve their visual search performance, in Experiment 4 the (possible) connection between the background cues and the color of the target was made more explicit. Specifically, at the end of each Epoch, participants were tested regarding their knowledge by having participants type out the most likely colors of the target given the background presented on the screen. Due to this methodology, participants would likely begin selecting the background cue on each trial after the first Epoch.

Method

Participants

Twenty-Seven participants (23 females; $M_{age} = 20.6$) from the University of Oklahoma participated in Experiment 4 for course credit (26 participants) or $10. All participants reported normal or corrected-to-normal vision. Two participants were excluded from the analysis due to a high error rate (error rate ≥ 15%) and one was excluded for having exceptionally long RTs as determined by having a mean RT value more than 3 standard deviations higher than the average for the mean of the collapsed 100, 60/40, and random conditions.

Procedure

The same procedure used in Experiment 2 was used in Experiment 4 with the following exception. At the end of each Epoch, participants were asked to indicate the most likely colors of the target (up to 4) given the cue. During this knowledge test, a background cue was presented (2004 ms) followed by a search array containing each of the different colors used in the experiment (see Figure 8).

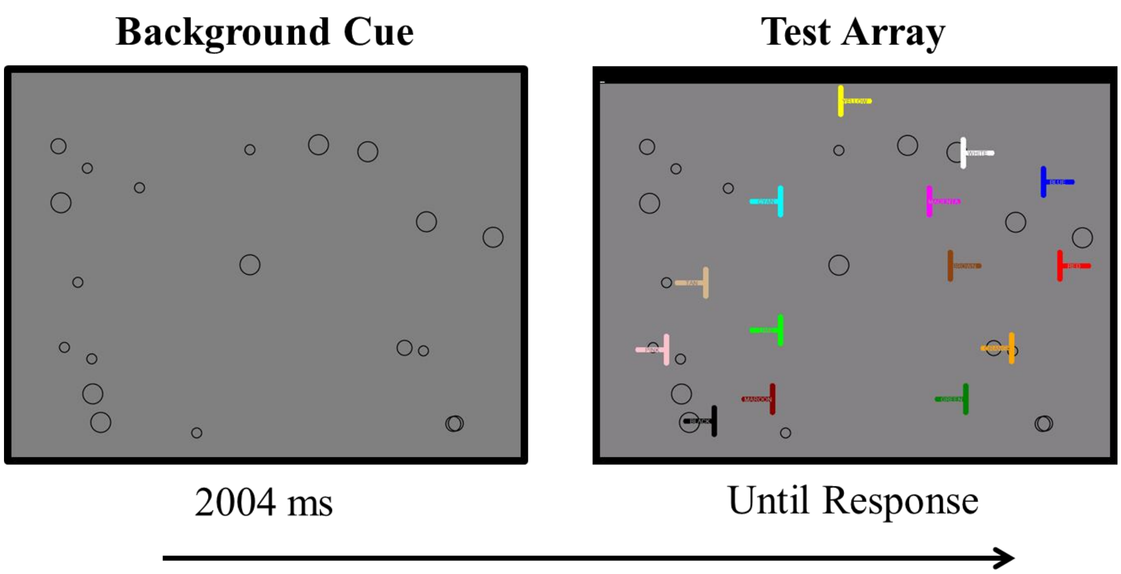

Figure 8: A schematic of the testing phase for Experiments 4 and 5.

Each color was a rotated "T" character and had the name of the color on the horizontal bar of the "T." Participants were asked to type out the colors from most likely to least likely given the background cue and to only type out the colors they believed to be associated with the background cue. For instance, if a participant believed that 2 colors were associated with a background cue they would only type out those colors.

Results

Error trials were excluded from analysis (2.3 %) as well as trials with RTs faster than 200 ms and slower than 10,000 ms (5.1%). Performance in the knowledge task varied significantly. Because of this, I split the participants into two groups based on their performance in the knowledge task. Participants were placed into a good knowledge test performers if they were able to name the colors associated with background 1 and background 2 cues and indicated only those colors (i.e., C1 for background 1 and C2 and C3 for background 2 (C2 or C3 could be typed in either order)). If participants were unable to do this at least once during the experiment (out of the 6 tests), they were placed into the poor knowledge test performance group. I first examined the RT performance for the good knowledge test performers.

A repeated measures ANOVA was calculated with Epoch (1-6) and cue validity (100, 60/40, Random) as within subject factors. A main effect was found for Epoch ($F(5, 80) = 34.076$, $p < .001$, $\eta^2 p = .680$) and cue validity ($F(2, 32) = 206.529$, $p < .001$, $\eta^2 p = .928$) such that participants were faster as Epoch and cue validity increased. A significant interaction was also observed between Epoch and cue validity ($F(10, 150) = 7.320$, $p < .001$, $\eta^2 p = .314$, see Figure 9).

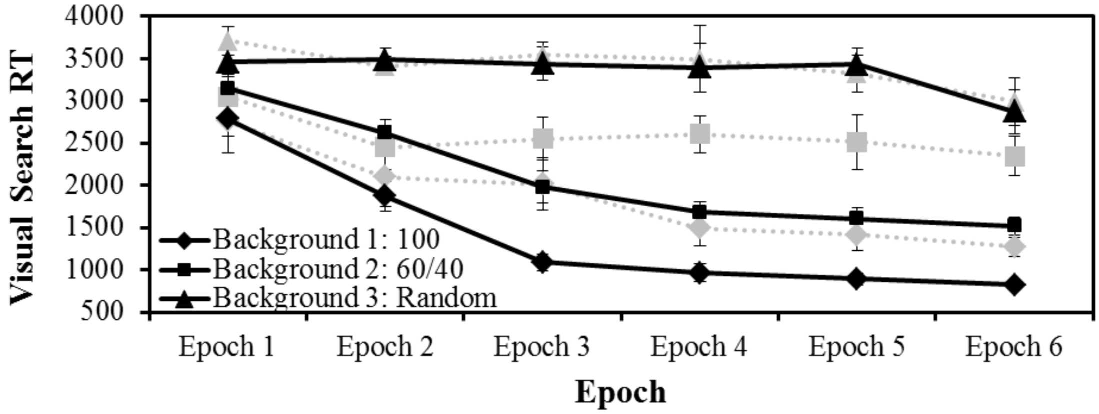

Figure 9. Reaction time performance as a function of Epoch and cue validity in Experiment 4. Error bars represent one standard error. Please note that the black represents good knowledge test performers and the gray represents poor knowledge test performers.

I next collapsed across the last 3 Epochs to compare RT performance for the different cue validity conditions. A within subjects ANOVA revealed a main effect of cue validity, $F(2, 32) = 204.719$, $p < .001$, $\eta^2_p = .928$ on RTs. Pairwise comparisons revealed a significant difference between the 100 (*M* =893.02) cue validity condition to the 60/40 (*M* = 1601.05) cue validity condition ($p < .001$) and the Random (*M* =3230.83) cue validity condition ($p < .01$). The 60/40 cue validity condition was also significantly different from the Random cue validity condition ($p < .001$).

I next examined the dominant and minor features associated with background 2 for the good knowledge test performers. A repeated measures ANOVA with target type (100, dominant, minor, and random) as a within subjects factor revealed a main effect, $F(3, 48) = 121.877$, $p < .001$, $\eta^2_p = .884$. Subsequent pairwise comparisons revealed that the dominant feature (*M* = 1426.7) was found significantly faster than the minor feature (*M* = 1967.9; $p < .001$). Additionally, the target was found faster when background 1 was the cue relative to the dominant feature being the target ($p < .001$).

The minor feature was found faster than the target in the Random cue validity condition ($p < .001$). This last effect reveals that participants are able to utilize multiple features in response to an environmental cue (c.f. contextual cueing effect, see Zellin et. al., 2011).

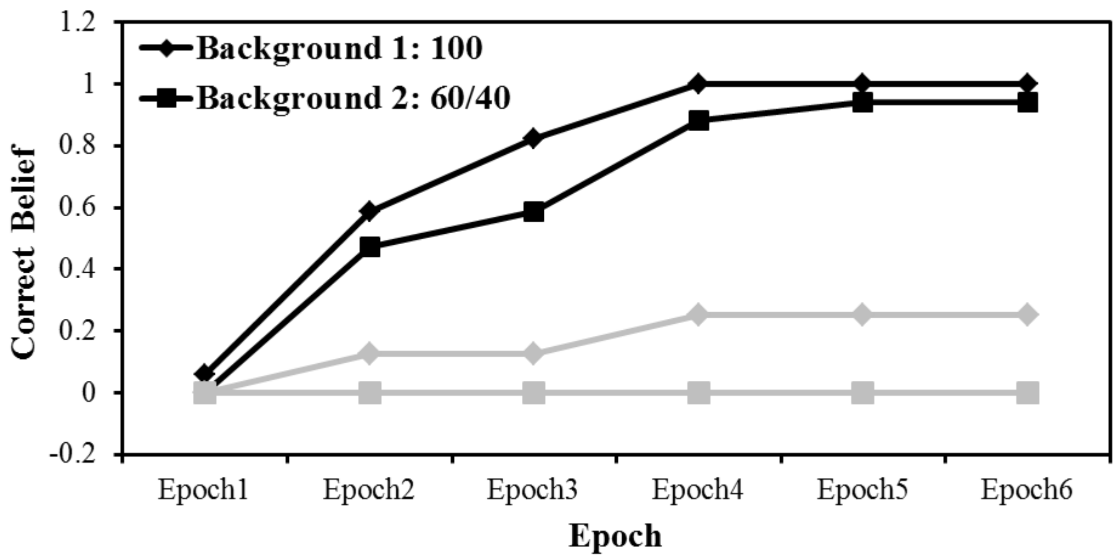

Figure 10: Correct beliefs plotted as a function of Epoch for Experiment 4. Note that the black represents good knowledge test performers and the gray represents poor knowledge test performers.

Figure 10 displays performance in the knowledge task. As can be seen, the good knowledge test performers were more likely to indicate the correct color(s) associated with a particular background as the experiment progressed and participants were near perfect for the last three Epochs (100% for the 100 cue validity condition and 92.2% for the 60/40 cue validity condition). To examine whether knowledge test performance would also lead to better performance in the visual search task, I next compared the RT performance for the participants in Experiment 2 to the participants in Experiment 4. Remember, comparing Experiment 2 to Experiment 3a revealed that participants were merely relying on base rate information to inform their search processes. Thus, comparing Experiment 4 to Experiment 2 will reveal whether having accurate knowledge regarding the relationship between the background cues and the colors of the target will lead to better (i.e., faster) visual search performance.

A main effect of cue validity was found ($F(1,32) = 71.1$, $p < .001$, $\eta^2_p = .683$) as well as a main effect for Experiment such that participants were faster in Experiment 4 than in Experiment 2, ($F(1,33) = 61.022$, $p < .001$, $\eta^2_p = .649$). An interaction between Experiment and cue validity was not observed, ($F(1,32) = .010$, $p = .921$, $\eta^2_p < .001$). A Post-hoc analysis revealed a significant difference when comparing the 100 cue validity condition in Experiment 4 to the 100 cue validity condition in Experiment 2 ($p < .001$) and also the 60/40 cue validity condition was significantly different across experiments ($p < .001$, see Figure 11). These results indicate that the good knowledge test performers in Experiment 4 were able to use the cues to reduce the complexity of the visual search task over and beyond the use of simple base rate information. However, not all participants were able to learn the background cue and target color connection, and I next examine RT performance for these participants (i.e., the poor knowledge test performers).

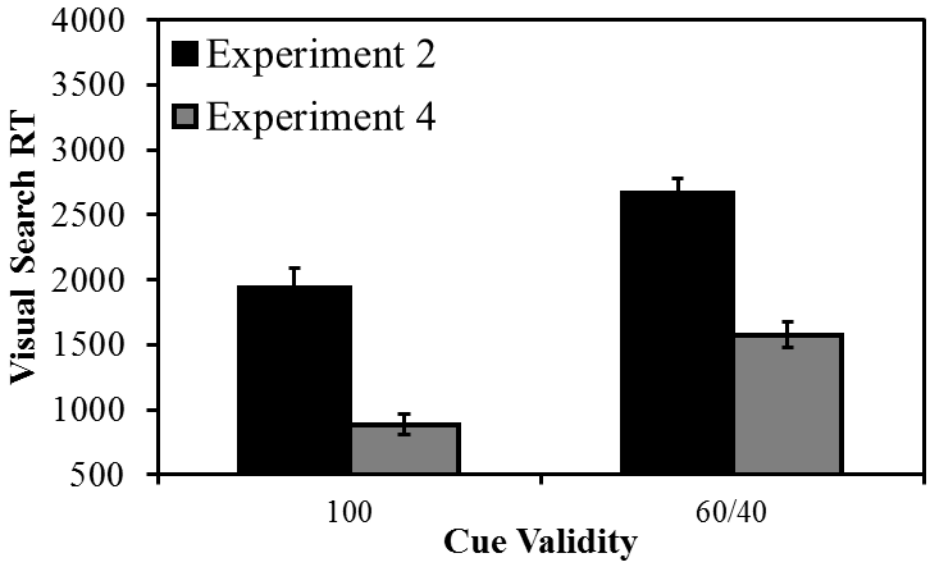

Figure 11: A comparison of the 100 and 60/40 cue validity conditions of Experiment 2 to the respective conditions for the good knowledge test performers of Experiment 4. Error bars represent one standard error.

A repeated measures ANOVA was calculated with Epoch (1-6) and cue validity (100, 60/40, Random) as within subject factors. A main effect was found for Epoch ($F(5, 35) = 4.730$, $p = .002$, $\eta^2p = .403$) and cue validity ($F(2, 14) = 17.852$, $p < .001$, $\eta^2p = .718$) such that participants were faster as Epoch and cue validity increased. A significant interaction was also observed ($F(10, 70) = 2.062$, $p = .039$, $\eta^2p = .228$ (see Figure 9).

I next examined RTs for the poor knowledge test performers for the last 3 Epochs of the experiment. A within subjects ANOVA revealed a main effect of cue validity $F(2, 14) = 19.059$, $p < .001$. A Bonferonni post hoc analysis revealed that despite not correctly indicating the target colors given the background cue, the 100 (M = 1394.69) condition was significantly different from the 60/40 (M = 2489.17), and Random (M = 3269.81) cue validity conditions (both p's < .01) but the 60/40 cue validity condition was not significantly different from the Random cue validity condition (p = .206). Note that the poor knowledge test performers had 0% accuracy for testing throughout the entire experiment and their RT performance for the 60/40 cue validity condition reflects this. Thus, it appears that the poor knowledge test participants in Experiment 4 were at least able to use some base rate information to improve visual search performance. I next examined whether this was over and beyond what participants in Experiment 2 were doing (i.e., merely relying on base rate information).

A main effect of cue validity was found ($F(1, 24)$ =52.875, $p < .001$, $\eta^2_p = .688$) as well as a marginal effect for Experiment such that the poor knowledge test performing participants were faster in Experiment 4 than the participants of Experiment 2, ($F(1, 24) = 3.704$, $p = .066$, $\eta^2_p = .134$). An interaction between Experiment and Cue Validity was not observed, ($F(1, 24) = 2.181$, $p = .153$, $\eta^2_p = .083$). A post-hoc analysis revealed that the 100 cue validity condition was not significantly different across groups (p = .31) nor was the 60/40 cue validity condition (p = 1.0). Thus, these results indicate that the poor knowledge test performers were more like the participants in Experiment 2 that relied on base rate information rather than the good knowledge test performers who were conditionalizing on background cue when delimiting the color(s) to be used to drive search when the array was presented. To test this, I next compared the RTs of the good knowledge performers of Experiment 4 with the poor knowledge test performers. Knowledge test performance (good, poor) was a between subjects variable and cue validity (100, 60/40) was a within subjects variable.

A significant main effect of cue validity ($F(1, 23) = 129.591$, $p < .001$, η^2_p = .849) as well as knowledge performance ($F(1, 23) = 29.332$, $p < .001$, $\eta^2_p = .560$) was observed. The good knowledge test performers of Experiment 4 were faster than the poor knowledge test performers and the target was found faster as cue validity increased. An interaction between cue validity and knowledge test performance type was also revealed such that there was a larger difference between the 60/40 condition across groups relative to the 100 cue validity condition, $F(1,23) = 8.928$, $p = .007$, $\eta^2_p = .280$. Although a between subjects analysis using a post-hoc Bonferonni test did not reveal a significant difference when comparing the 100 cue validity conditions of those participants in Experiment 4 who were able to identify the colors versus those that were unable to do so ($p = .11$), a significant difference was observed when comparing the respective 60/40 cue validity conditions ($p < .001$).

Discussion

In Experiment 4 when participants were clued into the possibility of a connection between the background cues and the target color, most participants were able to use this information to find the target. Specifically, as cue validity increased the good knowledge test performers were able to find the target significantly faster than the participants of Experiment 2 who were only relying on base-rate information. Thus, it appears that for the good knowledge performers, the test at the end of each Epoch was enough incentive for participants to select the background cues on each trial (after the first Epoch) as this selection process would lead them to be able to use the colors to drive search that have been associated with the background cue in the past. Additionally, it was found that two target features were able to be used to effectively find the target search array as evidenced by the finding that when the minor feature was found significantly faster when background 2 was the cue relative to when background 3 was the cue. This finding suggests a different cognitive process operating in Experiment 4 from that in contextual cueing studies (see Zellin et al., 2011). This difference is treated in the general discussion.

Not all participants were able to learn the relationship between the background cues and the target color, however. These participants were labeled as poor knowledge test performers and the results indicated that they were more like the participants of Experiment 2 than the good knowledge test performers of Experiment 4. I suggest that these participants simply did not understand the instructions and were merely aware that the target may more likely to be certain colors across trials (i.e., base rate information). Thus, these participants were only selecting the target on each trial and were not selecting the background cue and thus were not able to use the cues later in the visual search task (i.e., Epochs 4-6).

Chapter 7: Examining attentional guidance through eye movements

Although Experiment 4 revealed that the good knowledge test performers were able to use the cues to find the target effectively, Experiment 5 sought to replicate Experiment 4 while also obtaining other metrics pertinent to visual search. In Experiment 5 participants were eye tracked as they went through the task, allowing for the examination of scan path ratio. Scan path ratio is often used as a measure of efficiency in a visual search task and can be calculated based on the distance that a participant's eye travels during the entire trial. To calculate the scan path ratio, the distance traveled by the dominant eye for the trial goes in the numerator and this value is divided by the distance between the center of the screen and the center of the target in the visual search array. A lower value scan path ratio indicates more efficient search whereas a higher scan path ratio indicates less efficient search. It is hypothesized that scan path ratio will decrease as a function of increasing cue validity, mirroring the RTs from Experiment 4. Another eye track dependent variable that was measured was how often the target was the first item in the search array for the different cue validity conditions (e.g., Peterson & Kramer, 2001). The more often that the target is fixated first provides evidence of stronger attentional guidance. It is hypothesized that as cue validity increases, the target will be fixated first more often.

Method

Participants

Twenty-six participants from the University of Oklahoma participated in Experiment 5 for course credit or $10. Demographic information was not collected.

Procedure

The same procedure used in Experiment 4 was used in Experiment 5, with the exception that participants were eye tracked while going through the experiment. Eye tracking was conducted using an Eye Link 1000 with a sampling rate of 500 Hz with stimulus presentation and data recording controlled via Experiment Builder. Participants responded using the ResponsePixx box and were instructed to press the left button when the target was oriented 90^{o} counterclockwise and the right button when the target was oriented 90^{o} clockwise.

Results

Five participants were excluded from analysis due a high proportion of trials (greater than 25%) where the first fixation for the search array was too far from central fixation (19 mm from central fixation). Using the criterion used in Experiment 4, 5 participants were excluded due to poor knowledge performance in the knowledge task and these participants are not considered further. Sixteen participants were used for the analyses. For the remaining data, error trials were excluded from the analyses (1.9 %), trials with RTs faster than 200 ms and slower than 10,000 ms (1.4%), and finally trials where the first fixation were too far from central fixation at the onset of the search array (5.4%). Errors were not analyzed in any manner.

A repeated measures ANOVA was calculated with Epoch (1-6) and cue validity (100, 60/40, Random) as within subject factors. A main effect was found for Epoch ($F(5, 75) = 25.761$, $p < .001$, $\eta^2p = .632$) and cue validity ($F(2, 30) = 101.235$, $p < .001$, $\eta^2p = .871$) such that participants were faster as Epoch and cue validity increased. A significant interaction between Epoch and cue validity was also observed ($F(10, 150) = 16.631$, $p < .001$, $\eta^2p = .526$, see Figure 12).

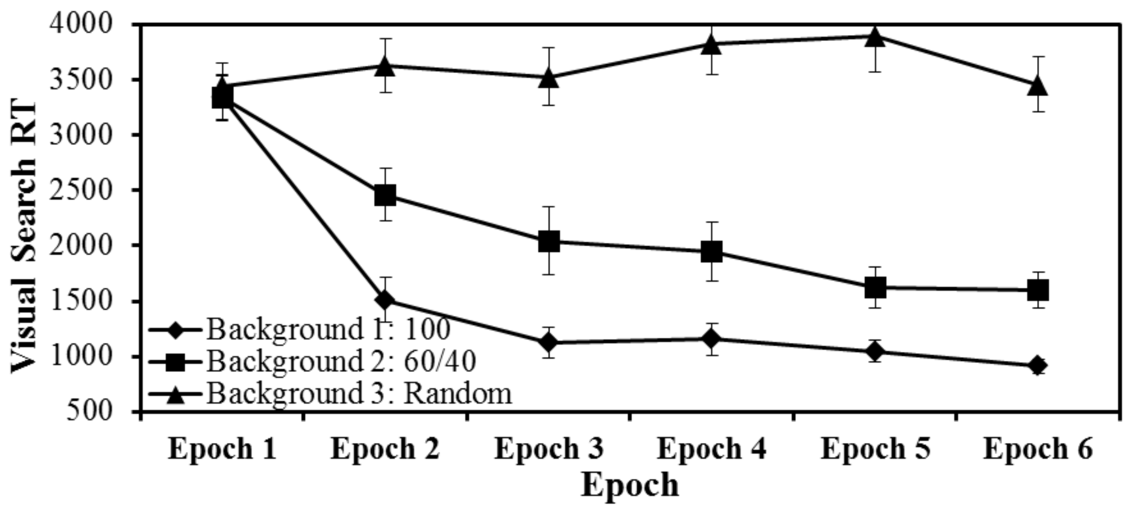

Figure 12: Reaction time performance as a function of Epoch and cue validity in Experiment 5. Error bars represent one standard error.

The last 3 Epochs were then collapsed across to compare performance for the last 3 Epochs. A within subjects ANOVA revealed a main effect of cue validity, $F(2,30) = 119.480$, $p < .001$, $\eta^2_p = .888$. Pairwise comparisons revealed a significant difference between the 100 (M =981.63) cue validity condition with the 60/40 (M = 1643.85) cue validity condition ($p = .001$) and the Random (M =3565.6) cue validity condition ($p < .001$). The 60/40 cue validity condition was also significantly different from the Random cue validity condition ($p < .001$).

As in Experiments 2 and 4, I next examined the dominant and minor features for background 2. A repeated measures ANOVA revealed a significant main effect of target type, $F(2, 45) = 83.303$, $p < .001$, $\eta^2_p = .847$. Pairwise comparisons revealed that the dominant feature ($M = 1379.8$) was found significantly faster than the minor feature ($M = 1863.4$; $p = .017$). There was a marginal effect such that the target was found faster when background 1 was the cue relative to when the dominant feature was the target ($p = .059$) for background 2. As in Experiment 4, when the minor feature was associated with the target for background 2, the target was found faster than the target for the Random cue validity condition ($p < .001$).

To ensure that the RT results of Experiment 5 were similar to Experiment 4, I next compared the results of Experiment 2 with the RT results from Experiment 5. A main effect of cue validity was found ($F(1, 32) = 44.288$, $p < .001$, $\eta^2_p = .581$), where there was a decrease in RT as validity increased, as well as a main effect for Experiment, such that participants were faster in Experiment 5 than in Experiment 2, ($F(1, 32) = 41.175$, $p < .001$, $\eta^2_p = .563$). An interaction between Experiment and cue validity was not observed, ($F(1, 32) = .091$, $p = .765$, $\eta^2_p = .003$). A post-hoc analysis revealed a significant difference when comparing the 100 cue validity condition in Experiment 5 to the 100 cue validity condition in Experiment 2 ($p < .001$) and also the 60/40 cue validity condition was significantly different across experiments ($p < .001$).

For the next analysis I examined the scan path ratio for participants. This was calculated by taking the total distance (in pixels) that the dominant eye traveled over the course of a trial and dividing that value by the distance between the center of the screen and center of the target (in pixels). The median value for each participant for each of the different cue validity conditions at each Epoch was calculated. As mentioned above, a lower scan path ratio indicates a more efficient search process and it was expected that scan path ratio would decrease as a function of increasing cue diagnosticity.

A within subjects ANOVA with Epoch (1-6) and cue validity (100, 60/40, Random) as within subject variables. A main effect was found for Epoch ($F(5, 75) = 12.664$, $p < .001$, $\eta^2 p = .458$) and cue validity ($F(2, 30) = 105.962$, $p < .001$, $\eta^2 p = .876$) such that participants were more efficient searchers as Epoch and cue validity increased. A significant interaction was also observed ($F(10, 150) = 10.721$, $p < .001$, $\eta^2 p = .417$, see Figure 13).

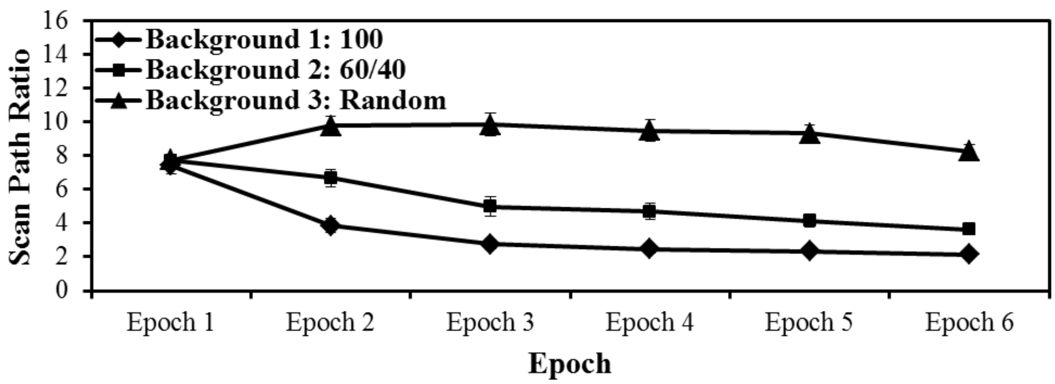

Figure 13: Scan path ratios as a function of Epoch and cue validity in Experiment 5. Error bars represent one standard error.

I then collapsed across the last 3 Epochs to compare the scan path ratios for the different cue validity conditions. A within subjects ANOVA revealed a main effect of cue validity, $F(2,30) = 101.725$, $p < .001$, $\eta^2_p = .871$. Pairwise comparisons revealed a significant difference between the 100 ($M = 1.71$) cue validity condition with the 60/40 ($M = 3.6$) cue validity condition ($p < .001$) and the Random ($M = 8.16$) cue validity condition (p < .001). The 60/40 cue validity condition was also significantly different from the Random cue validity condition (p < .001). Therefore participants searched more efficiently (i.e., lower scan path ratio) as cue validity increased.

I next examined the scan path ratios for the dominant and minor feature values for the background 2 cue to corroborate the RT evidence presented above. A repeated measures ANOVA revealed a main effect of target type, $F(3,45) = 66.8$, $p < .001$, η^2_p = .817. Pairwise comparisons revealed a significant difference between the dominant (M = 2.91) and minor (M = 4.52) features (p = .005). The target for the background 1 cue had a significantly lower scan path ratio compared to when the dominant feature (p = .015) was associated with the target for background 2. Finally, there was a lower scan path ratio when the minor feature was associated with the target for background 2 relative to the scan path ratio for the background 3 cue (p < .001). Thus, the scan path ratio aligns nicely with the RT results.

For the last set of analyses I examined how often the target was the first item fixated in the search array. A repeated measures ANOVA was calculated with Epoch (1-6) and cue validity (100, 60/40, Random) as within subject factors. A main effect was found for Epoch ($F(5, 75) = 32.744$, $p < .001$, η^2p = .686) and cue validity ($F(2, 30)$ = 62.05, $p < .001$, η^2p = .805), such that participants were faster as Epoch and cue validity increased. A significant interaction between Epoch and cue validity was also observed ($F(10, 150) = 12.672$, $p < .001$, η^2p = .458, see Figure 14).

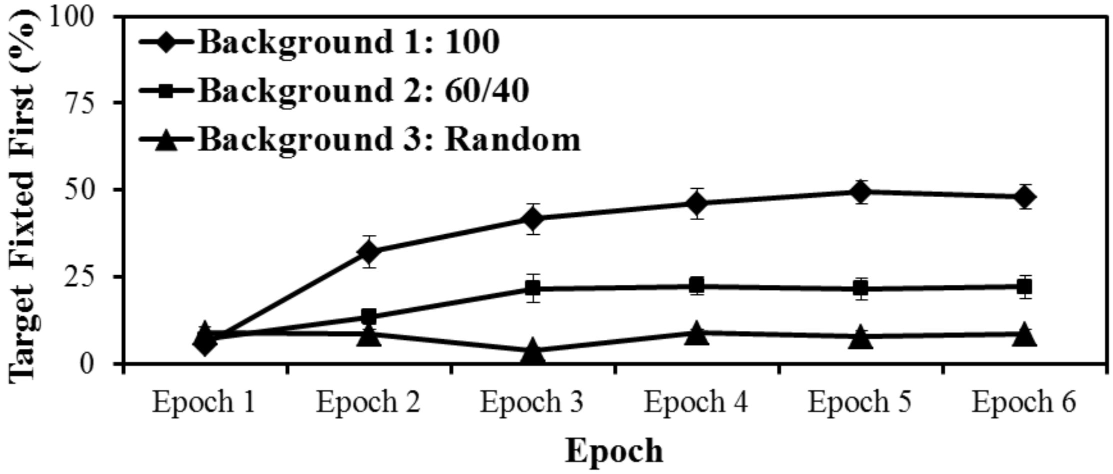

Figure 14: Percentage of time the target is the first item fixated in the search array as a function of Epoch and cue validity in Experiment 5. Error bars represent one standard error.

Next, I collapsed across the last 3 Epochs to examine the percentage of time the target was the first object fixated for the different cue validity conditions. A within subjects ANOVA revealed a main effect of cue validity, $F(2,30) = 64.459$, $p < .001$, $\eta^2_p = .811$. Pairwise comparisons revealed a significant difference between the 100 (M = 47.86%) cue validity condition with the 60/40 (M = 22.09%) cue validity condition ($p < .001$) and the Random (M = 8.5%) cue validity condition ($p < .001$). The 60/40 cue validity condition was also significantly different from the Random cue validity condition ($p < .001$). Based on these data, it seems evident that participants were strongly guided towards the target, particularly for the 100 cue validity condition.

For the last analysis I examined the how often the target was the first object fixated for the dominant and minor feature values. A repeated measures ANOVA revealed a main effect of target type, $F(3,45) = 43.7$, $p < .001$, $\eta^2_p = .744$. Pairwise comparisons revealed a significant difference between the dominant (M = 30.22%) and minor (*M* = 14%) features (p < .001). The target for the background 1 cue was fixated first more often than the dominant feature (*p* = .016). Finally, there was no difference in the percentage of time the minor feature was fixated first relative to the background 3 cue (*p* = .466). This last analysis is interesting because even though participants were rarely fixating the minor feature first they were still finding the minor feature significantly faster than the target for the random cue validity condition. This issue is explored in the discussion.

Figure 15 shows knowledge performance for the good knowledge test performers for Epoch and the 100 and 60/40 cue validity conditions in Experiment 5.

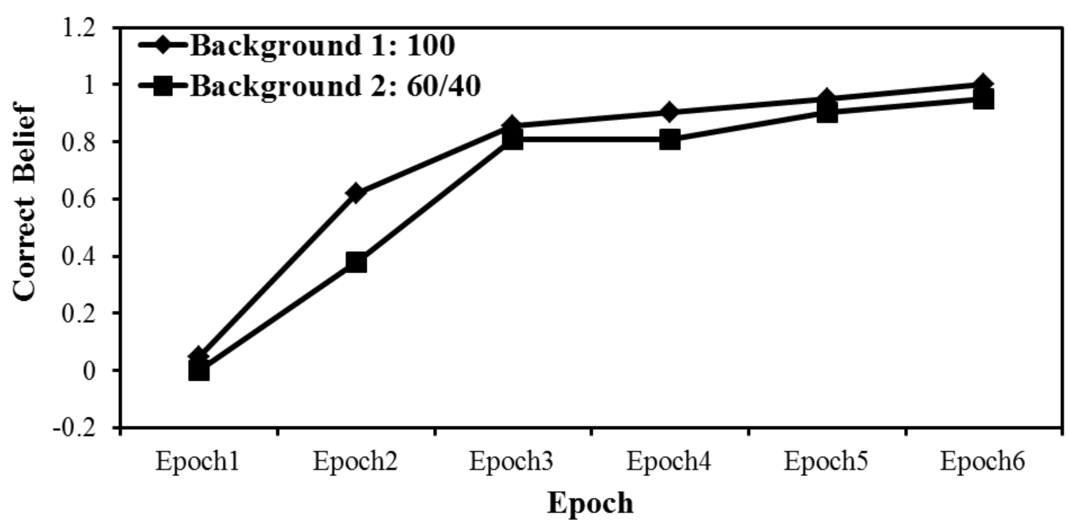

Figure 15: Correct beliefs plotted as a function of Epoch for Experiment 5. Note that the only good knowledge test performers are plotted.

<u>Discussion</u>

In addition to replicating the RT results from Experiment 4, Experiment 5 further showed that the good knowledge test performers were more efficient searchers as the diagnosticity of the cue increased. That is, participants traversed less space to find the target when the cue was highly diagnostic (i.e., background 1 and background 2) relative to when the cue was non-diagnostic (i.e., background 3). It is assumed that participants visited more items in the search array as diagnosticity decreased, thus increasing the total distance travelled throughout the trial and subsequently increasing the scan path ratio.

Another interesting aspect of the data for Experiment 5 was the percentage of time the target was the first item fixated after the onset of the search array. As presented above, the target was fixated roughly 45% of the time for the 100 cue validity condition and 20% of the time for the 60/40 cue validity condition. These data contrast with those of Peterson & Kramer (2001) who eye tracked participants during a standard contextual cueing procedure. The authors found that the target was fixated first for consistently mapped scenes on 11.3% of trials and 7.1% of trials for varied mapped scenes (note that in their study there were fewer items in each search array relative to Experiment 5). The discrepancy in the results suggest that attention was strongly guided towards potential target features given the memory prompts, even when the memory prompt was associated with more than one feature (i.e., the 60/40 cue validity condition). Another interesting aspect of the data was the finding that the minor target feature was not fixated first more often than the target in the random cue validity condition. This suggests that on most trials when background 2 was the cue participants were directing attention towards the dominant target feature at the onset of the search array. Even though the minor target feature was not fixated first that often, it was still found significantly faster than the target for the Random cue validity condition. Additionally, the scan path ratio was significantly lower for the minor target feature relative to scan path ratio for the background 3 (random) cue. These data suggest one of two likely possibilities: 1) either participants are retrieving multiple target features prior to the onset of the search array and directing attention towards those features in a systematic way (e.g., first check the dominant feature and then the minor feature) or 2) participants are only retrieving one target feature prior to the onset of the search array and then retrieve after that (e.g., participants first retrieve the dominant feature and if that is not the target they then retrieve another potential target feature in the middle of the trial). In the future it will be important to determine what participants are doing in the paradigm utilized in the present dissertation as there might be important behavior implications depending on whether participants are retrieving all possible relevant features or they are retrieving one feature at a time.

Beck, Hollingworth, and Luck (2012) investigated the issue of switching internal target representations (i.e., features in WM) in a paradigm where participants were provided with information regarding the color of the target in the form of a color cue prior to the onset of the search array. Participants were either informed to “search all” of one color (e.g., search all of the red items first before switching to the green items) or were informed to “switch between” colors (e.g., search for red and then green and then red…). The difference in this instruction produced a switch cost effect such that there was a longer fixation duration in the “search all” condition when participants next fixated a new color (e.g., participants had searched 6 red items and the longer duration was associated with the 6th fixation (relative to the previous 5 fixations) when the next fixated item was a green item) relative to the “switch between” condition. The authors argued that participants were “loading up” the next relevant feature into WM and thus experienced the cost in the “search all” condition. Another possible interpretation of the results is that participants were only keeping one item in WM in the “search all” condition and when they decided to switch representations they had to retrieve information from LTM and thus experienced a cost. This contrasts to the “switch between” condition where participants had both target representations in WM and thus did not have to retrieve information from LTM and did not experience any costs. Future research may want to use a similar paradigm as Beck, Hollingworth, & Luck in a paradigm where participants must use LTM to retrieve likely target characteristics. This methodology may help determine whether participants retrieve multiple target features prior to the onset of a search array or if only one target representation is ever active in WM at one time during the task even though retrieving multiple target features would most likely be useful for performing well in the visual search task.

Chapter 8: General Discussion

In the present dissertation I investigated whether participants would be able to use cue information to reduce the perceptual demands in a visual search task. Although Experiments 4 and 5 revealed that participants are indeed able to use cues that are probabilistic associated with target features (i.e., colors), Experiments 1-3b revealed that statistical regularities are not passively absorbed and exploited by the cognitive system. As mentioned above, Turke-Browne et al., (2005) found that selection is a crucial component when learning statistical regularities, even when these regularities are deterministic and have no probabilistic component (i.e., in their training phase the to be learned relationships always appeared in the same order). It is assumed that selection of the background cue on each trial was the crucial component that allowed the good knowledge test performers of Experiments 4 and 5 to use the background cue to inform their search process. It is unclear at present whether the deployment of different strategies to encourage selection of the background cues would be as effective as the testing in Experiments 4 and 5.

The results from the present dissertation suggest that the paradigm developed could be useful for the investigation of visual search where LTM is involved. As mentioned in the discussion of Experiment 5, it will be important for researchers to determine whether participants are retrieving multiple target features in response to background cues that are associated with multiple features. The reason for this is that when participants are asked to search for multiple objects there are differences in visual search behavior compared to when only one item is to be searched for (Beck, Hollingworth, & Luck, 2012; Menneer, Cave, & Donnelly, 2009; Stroud, Menneer, Cave, & Donnelly, 2012). However, this effect has not been explored in a context where participants must retrieve relevant target features themselves, making it a valid inquiry for future research.

Another important aspect of the results to be discussed is that participants needed to be explicitly aware of the contingencies between the background cues and the color of the target in order for search to improve. This difference contrasts with many of the findings in visual statistical learning where participants are not able to recognize the statistical regularities they have seen before but are able to take advantage of them in an implicit manner (e.g., Chun & Jiang, 1998; Chun & Jiang, 1999; Turke-Browne et al., 2005). As mentioned in the introduction, Chun & Jiang (1998) found that participants were not able to recognize visual arrays that they had seen many times before from those they had never seen before even though the repetition of the arrays (consistent mapping condition) improved visual search performance. Although it has been mentioned many times before that selection is a crucial aspect of statistical learning, it is unclear whether participants in the present experiment would be able to learn the relationship between the background cues and the colors of the target in a more implicit manner. For instance, if participants are occasionally tested regarding the background cue after a trial occurred (e.g., picking amongst several different backgrounds what the previous background cue was), then it is possible that learning the relationship between the background cues and the color of the target would occur at an implicit level of awareness. However, if implicit learning did occur, it is possible that participants would have difficulties in learning probabilistic relationships (e.g., the 60/40 condition from Experiments 2-5) as evidenced by recent contextual cueing studies.

Makovski & Jiang (2010) had participants go through a Chun & Jiang (1998) type contextual cueing paradigm. However, at the end of training the location of a target given a cue either remained in the same location or was moved from where it had been during training. The authors found that as the distance between where the target was during training increased, the contextual cueing effect decreased (i.e., less difference between consistent versus varied scenes), suggesting that participants had difficulty in re-learning a new target location given an old scene (these conclusions are similar to Zellin et al., 2011). Based on these results, it may be that participants are unable to learn probabilistic relationships to inform visual search at an implicit level when cues provide probabilistic information regarding critical aspects of the target (e.g., feature, location), although it is possible that given enough training (e.g., 10 experimental sessions) that participants may learn the associations. However, it is unclear whether increased training would make participants become explicitly aware of the contingencies (i.e., participants would recognize the cues and be consciously aware of the target locations given those cues).

The results from the dissertation indicate that there are possible avenues to be explored to understanding the relationship between LTM, WM, and attention. One of the major aspects explored is the degree to which participants need to be explicitly aware to learn the relationship between background cues and target features. Interestingly, Chun & Jiang (1998) reported that when they informed participants that there may be a relationship between the cues and the color of the target they had difficulty in using the cues in service of visual search. This contrasts with Experiments 4 and 5 in which participants need to be explicitly aware in order for the background cues to facilitate search processes. Future research will need to investigate why there are differences between the paradigm described in the present dissertation and those in contextual cueing.

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